Admission Physiology Criteria After Injury on the Battlefield Predict Medical Resource Utilization and Patient Mortality

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Background: Medical resources and resource allocation including operating room and blood utilization are of prime importance in the modern combat environment. We hypothesized that easily measurable admission physiologic criteria and injury site as well as injury severity calculated after diagnostic evaluation or surgical intervention, would be strongly correlated with resource utilization and in theater mortality outcomes.

Methods: We retrospectively reviewed the Joint Theater Trauma Registry for all battlefield casualties presenting to surgical component facilities during Operation Iraqi Freedom from January to July 2004. Data were collected from the composite population of 1,127 battlefield casualty patients with respect to demographics, mechanism, presentation physiology (blood pressure, heart rate, temperature), base deficit, admission hematocrit, Glasgow Coma Score (GCS), Injury Severity Score (ISS), operating room utilization, blood transfusion, and mortality. Univariate and multivariate analyses were conducted to determine the degree to which admission physiology and injury severity correlated with blood utilization, necessity for operation, and acute mortality.

Results: Univariate analysis demonstrated a significant ($p < 0.05$) association between hypothermia (T $<34°$C) and the subsequent requirement for operation and mortality. In addition, the outcome variable total blood product utilization was significantly correlated with base deficit ($r = 0.61$), admission hematocrit ($r = 0.51$), temperature ($r = 0.47$), and ISS ($r = 0.54$). Using multiple logistic regression techniques, blood pressure, GCS, and ISS together demonstrated a significant association ($p < 0.05$) with mortality (area under ROC curve = 95%). Multiple linear regression established that blood pressure, heart rate, temperature, hematocrit, and ISS had a collective significant effect ($p < 0.05$) on total blood product utilization explaining 67% of the variance in this outcome variable.

Conclusion: Admission physiology and injury characteristics demonstrate a strong capacity to predict resource utilization in the contemporary battlefield environment. In the future, such predictive yield could potentially have significant implications for triage and medical logistics in the resource constrained environment of war and potentially in mass casualty and disaster incidents in the civilian trauma setting which will likely have mechanistic similarity with war related injury.

Key Words: Combat, War, Resources, Outcome, Predict, Blood, Mortality.

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Developing a means to forecast critical medical resource requirements and casualty outcomes during combat operations is a subject of intense interest and scrutiny. Resource allocation in an active theater of war is contingent upon many factors such as medical capability, trauma capacity, operational conditions, operational tempo, and mass casualty. The essential and finite resources that are in limited supply in the resource-constrained environment of combat include blood and operating room availability and utilization.

Historically, the majority of military casualty and outcome data, including disease (medical disease), nonbattle injury (injury on the battlefield not incurred in conflict with the enemy), and battle injury, has been collected retrospectively. These retrospective reports predict gross casualty load based upon gross topography, geography, weather, and a number of associated nonspecific factors, but do not identify human physiologic or anatomic variables that are useful in predicting individual and overall medical resource utilization. Blood transfusion was one of the most important medical advances of World War I.[1] During subsequent conflicts, blood utilization and transfusion techniques were refined and transfusion volumes were recorded. The record of the number of transfused units was mainly used for logistical planning of medical supplies to match supply with demand. Despite this important information requirement, no systematic studies have evaluated variables that predict blood use in combat. In addition, no data exists, based on a Medline search from 1965 to the present, to predict the necessity for operations, operative time, and individual casualty outcomes. The objective of this study was to evaluate the potential to predict medical resource use, and acute mortality outcomes, in a theater of war, using easily measurable anatomic and physiologic admission criteria, combined with injury site and injury severity.

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METHODS
Study Design and Subjects

This comparative and correlational study was performed using data gathered from a 7-month (January 2004 through July 2004) period of active combat operation during Operation Iraqi Freedom. The purpose of this study was to determine the degree to which physiologic parameters assessed at admission correlated with three battlefield Level III hospital outcomes (dependent criterion variables): acute mortality, whether an operation took place, and use and quantity of red blood cell products. Level III hospitals are military medical units such as the Army Combat Support Hospital (CSH) with surgical resources, advanced diagnostic capability, and extended intensive care and medical holding capabilities. Eight independent variable data elements were compiled for this analysis: heart rate (HR), blood pressure (BP), temperature (T), hematocrit, pH, base deficit, Glasgow Coma Score (GCS), and Injury Severity Score (ISS).

Inclusion criteria were all patients evaluated at the Combat Support Hospitals. The included sample population consisted of 1,127 patients with nearly complete or complete medical records admitted to Level III component Combat Support Hospital (CSH) units located throughout the country of Iraq. The sample included US coalition, civilian, and enemy combatant casualties. Excluded from the analysis were 150 admitted patients with limited or no data in their medical records at the time of review.

The medical records were evaluated and pertinent predictor and criterion data were extracted by the authors. The data analyses were done independently by the US Army Institute of Surgical Research. The manuscript was screened for military operational security by the US Army Office of the Surgeon General.

Analyses

For univariate analyses, dependent variables were correlated with independent variables and analyzed by Pearson correlation coefficients. In addition, these data were also analyzed using independent samples t test methodology to determine differences among variables.

For multivariate analyses comparing continuous variables, multiple linear regression was used to determine the degree to which independent variables exerted their collective influence on the criterion variables. Categorical variables were represented as percentages and compared by using a Pearson χ^2 test. Multiple logistic regression was used to identify the physiologic variables that had significant effect on the dichotomous variable of mortality. SPSS for Windows was used for data management and statistical analysis (SPSS Graduate Pack for Windows 12.0, SPSS Inc., Chicago, IL, 2003). A $p < 0.05$ was considered significant for all statistical analyses.

The US Army Institute of Surgical Research Institutional Review Board approved this study before data collation and analysis. The conclusions of this study do not necessarily constitute the opinions of the United States Army or the United States Department of Defense.

RESULTS

With respect to mortality, all of the physiologic variables, except for HR ($p = 0.37$), were significantly different between nonsurvivor and survivor groups (see Table 1). In addition, significant correlations between mortality and each of the admission data criteria is demonstrated in Table 2. All values are statistically significant, except for heart rate. The survival rate was significantly different between normothermic (97.5%) and hypothermic (75%) groups ($p < 0.05$). Regarding the need for an operation, significant differences were found for all of the physiologic variables ($p < 0.05$), except for GCS ($p = 0.74$), between need for an operation or not. The need for operation was different between the hypothermic (87.5%) and normthermic (64.5%) groups ($p < 0.05$). Therefore, analysis of the data demonstrated a statistically significant association ($p < 0.05$) between hypothermia (T $< 34°$C) and the subsequent requirement for operation in theater. Total red blood cell product transfusion was cor-

Table 1 **Prediction of Mortality**

Characteristic	No Mortality	Mortality
BP	125 ± 17*	79 ± 38*
HR	90 ± 19	84 ± 34
T	36.8 ± 1.0*	34.5 ± 1.6*
GCS	14.4 ± 1.9*	5.5 ± 4.5*
Hematocrit	38.1 ± 7.1*	25.8 ± 8.7*
pH	7.31 ± 0.09*	7.07 ± 0.14*
Base deficit	3.3 ± 4.1*	10.2 ± 6.1*
ISS	9.9 ± 7.5*	23.2 ± 8.2*

* Values are statistically significant ($p < 0.05$).
Results analyzed by independent samples t test. Values expressed as means.
BP, blood pressure; HR, heart rate; T, temperature; GCS, Glasgow Coma Score; ISS, Injury Severity Score.

Table 2 **Association of Mortality, Operation, and Blood Utilization with Predictor Variables**

Characteristic	Mortality	Operation	Blood Utilization
BP	−0.30*	−0.08*	−0.38*
HR	0.05	0.14*	0.34*
T <34	0.23*	0.09*	0.34*
T	−0.25*	−0.21*	−0.47*
GCS	−0.50*	0.01	−0.16*
Hematocrit	−0.25*	−0.18*	−0.51*
pH	−0.43*	−0.13*	−0.56*
Base deficit	−0.47*	0.16*	0.61*
Blood loss	−0.48*	0.05*	0.71*
ISS	−0.37*	0.17*	0.54*

* Values are statistically significant ($p < 0.05$).
Values expressed as Pearson correlation coefficients (r).
BP, blood pressure; HR, heart rate; T, temperature; GCS, Glasgow Coma Score; ISS, Injury Severity Score.

related with base deficit ($r = 61$), hematocrit ($r = 0.51$), temperature ($r = 0.47$), and ISS ($r = 0.54$), with a significance level of $p < 0.05$.

Because no individual parameter uniquely predicted outcomes in any of the dependent variables, multivariate analyses were utilized in an attempt to demonstrate the collective association of independent variables. Multiple logistic regression was used to identify the physiologic variables that had a significant effect on mortality and necessity for operation. A model based on 865 of the patients, from whom all BP, GCS, and ISS, data were available, was analyzed. In this analysis, BP, GCS, and ISS together, were associated with mortality ($p < 0.05$) with an area under the ROC curve of 95%. Notably, when analyzed together, blood pressure, heart rate, temperature, hematocrit, and ISS were significantly associated ($p < 0.05$) with total blood product utilization (multiple linear regression; $r^2 = 0.67$).

DISCUSSION

The use of blood to resuscitate injured patients during World War I revolutionized the care of soldiers injured on the battlefield. Despite this advance, there is no quantitative evidence in the military or medical literature to predict the blood or resource utilization or predict the outcome of an individual injured soldier. Blood utilization and outcome predictions after injury are available in the civilian trauma literature.[2–4] However, it is difficult to extrapolate those predictions into the battlefield scenario, because types and patterns of injury during warfare are higher kinetic energy injuries than those seen in the majority of civilian practice situations. Bellamy characterized the wounding patterns and outcomes of combat injured soldiers in Vietnam. However, the results of this effort could not adequately reflect resource utilization because of the inherent limitations of the database.[5–7] In general, military reporting of injuries, use of resources (including blood products), and outcomes occurs on a gross scale and does not account for individuals. After the Desert Storm conflict, the US Department of Defense sought to quantify the medical resource demands of the theater of war, but only had limited success because of the relatively short nature of the conflict.[8–10] During the current period of armed encounter in southwest Asia, numerous articles have been written about the medical care of soldiers wounded in war,[11–18] but none has specifically evaluated medical resource utilization or made attempts to predict patient outcomes based upon data. The novel knowledge developed from this investigation was the association between admission injury physiology and the utilization of medical resources and outcomes in individual patients wounded in a battlefield environment.

The limitations of the study are that the data were collected in an environment that is associated with some missing data elements, either from loss or noncollection of data, because of patient acuity, secrecy, or military operational issues. Twelve percent of admissions available for study were noted to have limited or no data to interpret. In addition, in

the included study population, approximately 10% of the data elements were unable to be extracted from the documentation. However, our assumption is that these sources of no data or missing data were randomly distributed throughout the data set and therefore would not significantly impact the statistical analysis of our study. Given the nature of the data collected from real world military operations in theater, missing data are to be expected. While our results are promising in determining the relationship between physiologic data and the use of finite resources available on the battlefield, such as the necessity for operation, operative duration, the use of blood and blood products, and mortality, the missing data limit these analyses. Future data collection, data mining, and analyses should focus on gathering high quality, complete data sets so that a thorough examination of the effects can be determined.

The findings in this study set the stage for predicting battlefield medical resource requirements in the future. The utility of this analysis is that it is one of the most comprehensive physiologic data analyses in the history of warfare. Among our major goals were to determine the predictive nature of admission physiology for battlefield mortality and blood usage, since both are large determinants of medical resource utilization in war. This is a crucial distinction since extrapolation of the civilian literature is not reliable secondary to the fact that military wounding patterns, especially explosive associated injuries, are fundamentally different from those seen in the civilian arena. Another potential value of this analysis will be to develop model criteria on which to base the mobilization of advanced therapeutic strategies to mitigate resource utilization such as early use of Factor rVIIa, initiation of fresh whole blood drives, early resuscitative use of plasma component therapy, institution of massive transfusion protocols, etc.

From our analyses, easily measurable physiologic variables, including temperature, hematocrit, and base deficit, as well as the anatomic characteristics of ISS, were soundly correlated with resource utilization in the contemporary battlefield environment. In the future, the use of such predictive physiologic data could be very useful for triage and medical logistics in the resource constrained environment of war.

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